Platform Competition and Broadband Uptake: Theory and Empirical Evidence from the European Union*

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Abstract

Broadband access provides users with high speed, always-on connectivity to the Internet. Due to its superiority, broadband is seen as the way for consumers and firms to exploit the great potentials of new applications. This has generated a policy debate on how to stimulate adoption of broadband technology. One of the most disputed issues is about competition policies: these may be intended to promote competition in the Digital Subscriber Line (DSL) segment of the market (intra-platform competition), or to stimulate entry into the market for alternative platforms such as cable access or fiber optics (inter-platform competition). Using a model of oligopoly competition between differentiated products, our paper explicitly studies the effect of inter and intra platform competition on the diffusion of broadband access. The implications of the model are then tested using data from 14 European countries. The econometric evidence confirms the results of the theoretical model and indicates that while inter-platform competition drives broadband adoption, competition in the market for DSL services does not play a significant role. The results also confirm that lower unbundling prices stimulate broadband uptake.

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1 Introduction

The increased importance of information and communication technologies (ICT) as *the* major "General Purpose Technology" underlying the knowledge economy and, consequently, the rapid increase in investment in ICT, are considered by many as the key factor of the acceleration of productivity growth experienced by the United States during the last decade. Probably, of the many technologies that fall under the ICT umbrella, Internet is the one that has had the biggest impact in terms of cost savings and profitability increases in business.[1]

It is easy, then, to understand why Internet policy is playing a predominant role in many governments' agendas; the European Council, recognizing that the contribution of ICT to growth in Europe was too low and that much more could be expected, set in March 2000 the so-called "Lisbon strategy", aimed at making the European Union the most competitive and dynamic knowledge-based economy by 2010. To achieve this goal, the European Commission and Council draw and endorsed the *e*Europe 2002 action plan, focused on extending Internet connectivity and on reducing access prices.

In order to generate growth, connectivity needs to be translated into economic activities; hence the strategic importance of ICT for delivering large benefits to consumers in terms of new or improved products and services.[2] The European Council consequently endorsed the *e*Europe 2005 action plan. The plan is directed at stimulating services, applications and content capable of creating new markets and reducing costs, thanks to two new technological developments (deemed able to further expanding the potentialities of the Net): multi-platform access/convergence and broadband. For this reason, the main objective of the 2005 action plan is to get a widespread availability of broadband access at competitive prices in Europe by 2005.

Broadband diffusion policies are being put in place not only in consideration of the economic and social relevance of providing business and residential users with high speed access technologies, but also because there is a widespread concern that, although some disagree, broadband diffusion is taking place too slowly, or at least more slowly than originally predicted.[3]

[1] Varian et al. (2002) estimated that the adoption of Internet business solutions had yielded to US organizations, from the first year of implementation through 2001, cumulative cost savings of $155.2 billion and increased revenues of $444 billion.

[2] Crandall et al. (2002), for example, report that in US consumer benefits from universal broadband deployment, that is to say 94% of US households, which is the current level of telephone service, could easily be $300 billion a year and that 50% deployment would result in benefits of around $100 billion annually (benefits increase nonlinearly due to network effects).

[3] Nonetheless, empirical evidence shows that broadband take-up is actually happening quite at a fast pace relative to the adoption of similar communication technologies. For example, OECD (2003b) shows that at the end of 2003, seven years after the introduction of broadband access services, the number of broadband subscribers across OECD

Public initiatives implemented by central and local governments to stimulate broadband adoption can be classified in two broad categories: i) policies aimed at assisting the build up of broadband networks and ii) policies aimed at enhancing competition through telecom markets openness and access to infrastructures.

All policies directed at financially assisting telecommunication providers,[4] at establishing public-private partnerships (i.e. through public sector demand aggregation) and at building government-owned networks, fall within the first category. On the other hand, pro-competitive policies put into place by regulatory authorities such as compulsory unbundling of the local loop, shared access and wholesaling aimed at stimulating market-entry and at providing incentives to reduce prices, fall into the second category.

There is a general consensus on the idea that competition is the main driver of the adoption of broadband technologies (see e.g. OECD, 2001, 2002, 2003a). In these official documents particularly debated is the issue of the different available options to induce competition in the market for broadband access. In particular, whether competition should be introduced and promoted between different technological platforms able to offer broadband access (inter-platform competition); or within the same platform (intra-platform competition).[5]

The aim of this paper is to analyze the role of competition in promoting broadband adoption. Using a model of oligopoly competition between differentiated products, our paper explicitly studies the distinct effects of inter and intra-platform competition on the diffusion of broadband access. The empirical evidence, using data available for 14 European countries, supports the theoretical predictions of the model and establishes inter-platform competition as the main driver for broadband adoption while competition within the DSL segment of the market seems to play a less significant role. Our evidence also confirms that a lower price of local loop unbundling stimulates broadband, while granting rights of way and digging permits to Internet broadband providers through a central authority has not played a significant role.

The remainder of this paper is structured as follows: in Section 2 we describe the most common broadband technologies, while Section 3 briefly reviews the literature on broadband diffusion. The theoretical model of oligopoly competition is introduced in Section 4, and its main implications are empirically tested in Section 5. Finally, in Section 6 we draw some concluding remarks. All the proofs are contained in the Appendix.

countries exceeded by a considerable amount that of subscribers to mobile phone services, to analogic and Individual Subscriber Digital Number (ISDN) dial-up access services at the same stage of market development.

[4]Financial support may be provided either directly (through tax incentives, low interest loans and subsidies) or indirectly (through transfers to municipalities or end users).

[5]Given the actual state of the market for broadband access, this form of competition seems to be relevant only within the DSL segment of the market.

2 Broadband technologies

Despite all the documented interest in promoting broadband access, there is still no agreement on the definition of broadband. In fact, definitions given by governments and international institutions usually vary. For example, the International Telecommunications Union defines broadband as a technology providing a transmission capacity that is faster then primary rate ISDN (1.5 or 2 Mbps), while OECD defines broadband as a technology providing downstream speed in excess of 256 Kbps (and upstream access speed in excess of 128 Kbps). Other governments and institutions, given the fast pace of technical progress in ICT, prefer not to specify any speed or technical requirement, and their definitions mainly rely on the services that can be provided over broadband. In this paper, given the broad variety of broadband products delivered over different networks available to end users, we adopt a an unrestrictive definition. Broadband is identified with any access technology that guarantees the final customers connections (in terms of speed of data transfer) to the net of greater quality than traditional analogic or ISDN modems dial-up technologies. All the technologies briefly described below satisfy our definition.

Digital Subscriber Line (DSL) The most popular broadband technology, it converts the standard telephone line into a high speed digital line by transmitting data at higher frequencies than those used for voice. For this reason DSL technologies allow for simultaneous use of voice telephony and data services. There are various forms of DSL: Asymmetric DSL (ADSL), High Rate DSL (HDSL), Symmetric DSL (SDSL) and Very High Data Rate DSL (VDSL), which are able to provide connection speeds ranging from 256 Kbps to 52 Mbps.

Cable modem A broadband technology that uses access lines for cable television (CATV). Although traditional CATV networks need to be upgraded with a separate voice line to provide interactive communication services like telephony and Internet access, new networks use the same coaxial cable to provide simultaneous transmission of data, television and voice. Connection speeds range from 1 to 10 Mbps.

Fibre to the home (FTTH) A Fibre optic technology similar to standard cable that allows for transmission speeds of up to 10 Gbps. Fiber optic cables are rolled out up to home of the consumer and can carry video, data, voice and interactive video-telephone services.

Satellite A broadband technology that uses satellite TV equipment to carry data. At the moment the majority of services based on satellite technology are one-way (i.e. they only allow for downstream transmission) and need a dial-up connection for the return channel. The downstream speed ranges between 300 Kbps and 2 Mbps. This technology is considered to be particularly effective for servicing rural areas where other technologies are too expensive to be put in place.

Fixed Wireless Access (FWA) A technology, initially deployed as an alternative to the local copper loop, which uses radio links between a base station and a receiving antenna located in the customer's premises. It allows for simultaneous transmission of voice and data and can reach speeds of over 2 Mbps.

Power lines communications (PLC) A broadband technology that relies on the existing electricity distribution network to transmit data at speeds comparable to those offered by DSL. This technology is still in the testing phase of development and, given the ubiquity of the power network (as e.g. satellite), looks particularly promising for deploying broadband in rural areas.

In addition to these technologies listed above there are a few others belonging to the family of mobile technologies (e.g. "third generation") and some other defined as "nomadic" (e.g. radio-LANs). Although very promising in terms of connection speed and deployment, they are, like FWA and PLC, still confined to a small number of adopters. It is for this reason that in our empirical analysis we will use data concerning only DSL, cable, fiber and satellite technologies.

3 Review of the literature

Broadband is still at its infancy and there are only few empirical studies available on broadband diffusion. Bauer et al. (2003) presented a cross-national study of broadband uptake in the 30 OECD countries. Due to problems of data availability which restricts the analysis to year 2001, the authors estimate a cross sectional model which does not capture the dynamic evolution of the broadband market. The aim of the authors was to study the main drivers influencing broadband penetration; among the regressors they included the price of broadband, the price of dial-up services and a variable indicating the competitive conditions in the broadband market. Quite surprisingly, all these variables came out to be statistically insignificant.[6] This result is probably due to the lack of time–series data. Like any process of new technology diffusion, broadband adoption is a dynamic process that evolves through time and this crucial feature is not taken into account in the estimated cross-sectional model.

An interesting investigation, more closely related to ours, is presented in Aron and Burnstein (2003). These authors estimate the influence of availability, competition and demographics on the

[6]The fully specified model yielded significant parameters only for two variables: population density and a variable called "preparedness", intended to capture the attitudes of a population towards information technology.

adoption of broadband technology in 46 US states. The paper focuses on the effect of inter-platform competition on broadband penetration relative to the effect of simple broadband availability (i.e. when only one platform is available); other variables included in the regressors are the price for unbundled local loop, the number of Internet access and the level of education. The authors find that inter-platform competition, mainly between cable and DSL technologies, has a positive and significant impact on broadband adoption. Again, the model estimated by Aron and Burnstein (2003) is a cross-sectional one and therefore it is a static model; furthermore, apart from the role of local loop unbundling, the authors do not explicitly analyse the impact of intra-platform competition on broadband uptake, which represents a relevant policy issue currently under scrutiny.

Garcia-Murillo and Gabel (2003) study the stimulating role of unbundling policies and other regulatory activities in local telecommunications. Their study includes 135 countries, with observations restricted to the year 2001. In their paper, the authors do not distinguish between inter and intra-platform competition when trying to estimate the determinants of broadband adoption. Quite surprisingly, Garcia-Murillo and Gabel do not find evidence of a positive role of unbundling policies towards broadband adoption; stronger evidence is found on the role of competition.

A different issue is tackled in Hausman et al. (2001) where the authors focus on the definitions of the boundaries of the broadband market. The aim of the paper is to understand the economic incentives of the providers of broadband access to limit the usage of broadband access and to verify the existence of significant providers' market power. A related and extremely debated issue is then to test the hypothesis that narrowband and broadband access are two separated markets; interestingly, Hausman et al. (2001) show that the price of narrowband dial-up access does not constrain the prices charged for broadband access, thus supporting the hypothesis that markets are separated.

Finally, various papers use population survey data to analyse the influence of demographic characteristics on individual's decisions to adopt broadband; Stanton (2004) and Rappoport et al. (2002) are two of the most recent papers of this emerging literature.

The picture emerging from the reviewed literature seems to be that the determinants of broadband adoption are still a question open to debate; in particular there are no empirical studies providing evidence on the impact of different competition policies on the adoption of broadband access technologies in a more dynamic context. In our paper we focus on the role of inter-platform versus intra-platform competition and on the influence of unbundling policies; the analytical results of a model of platform competition are outlined in the next section.

4 A simple model of platform competition

In order to stimulate adoption of broadband technologies, governments have adopted various initiatives usually intended to promote competition in the access market.

As previously mentioned, a common practice to entice competition in the market for broadband access services is to mandate incumbent telecom carriers to unbundle their local loop and to provide interconnection to any Internet Service Provider (ISP) demanding access at a predetermined-regulated price. Since local loop unbundling allows competitive ISPs to provide DSL services resting on existing network infrastructure, it represents the easiest and the quickest policy to stimulate entry into the market for broadband-DSL services. Alternatively, governments may promote competition into markets for cable or fiber optics access through investment subsidies or tax reductions. In this case, cable and fiber optic providers need to incur in relevant investments to build their new infrastructures and this makes these alternative forms of broadband access of less immediate availability to final customers.

It is often claimed among practitioners and policy makers that broadband adoption can be stimulated more effectively promoting competition between different platforms (inter-platform competition), rather than focusing on the market for DSL services (intra-platform competition).[7] One of the aim of the paper is to look for a theoretically supported empirical evidence to this claim. For this reason we devote this section to develop an extremely stylised model of intra-platform vs. inter-platform competition; the scope of this model is to provide a simple theoretical background for the empirical analysis conducted in the next section.

We proceed by following a standard model of oligopoly competition between differentiated products. For the sake of simplicity, suppose that broadband access is provided only through two technologies, i.e. DSL and cable; furthermore, let us assume that DSL and cable access are provided by n and m firms respectively. Finally, according to the observation that the market for DSL is generally more competitive than the market for alternative technologies, we also assume that $n > m > 0$.

Since the main product differentiation across Internet providers is in the quality of the access that they guarantee to their customers (i.e. the speed of connection), it is reasonable to assume homogeneity between firms belonging to the same technology and product differentiation across technologies. Applying a standard approach of product differentiation to this framework,[8] demand for DSL and cable technologies can be represented respectively as

$$p_d = \alpha - \beta Q - \gamma Y,$$

[7] See DotEcon and Criterion Economics (2003).

[8] See Shy (1995).

and

$$p_c = \alpha - \gamma Q - \beta Y,$$

where $Q = \sum_i^n q_i$ and $Y = \sum_j^m y_j$ represent the total amount of DSL and cable access demanded, q_i and y_j denote the amount of access provided respectively by the individual firm i and j, and finally p_d and p_c refer to the respective prices.

Imperfect substitutability across technologies is easily incorporated by assuming that the own price effect dominates, i.e. $\beta > \gamma > 0$: the impact of increasing DSL (resp. cable) access on the price for DSL (resp. cable) is larger than the effect of the same increase in cable (resp. DSL).

On the cost side, each ISP providing DSL services has to pay the incumbent firm for the unbundled local loop. The price of the local loop is usually made of a fixed and a variable part, where this latter depends on the amount of bandwidth purchased. For the sake of simplicity, we do not explicitly include the one-off charge in the model and consider a constant variable and marginal access charge, indicated by c.

A firm providing cable broadband does not need access to the local loop of the telecom network; as it has been already discussed above, although cable providers often lease lines from the incumbent telecom operator, they mainly have to build their own infrastructure to serve the market. Formally, we assume that a cable provider does not have marginal cost but only a fixed cost of entry, indicated by F.[9]

Our framework is extremely stylized. In particular, it should be noted that we do not explicitly model the presence of an incumbent firm; this is equivalent to assume that the incumbent telecom operator receives the payments for unbundling its local loop from DSL firms, but it does not compete with them in the broadband market. This is clearly unrealistic, but it helps to keep the model tractable. Also, despite an increased complexity, the model with an incumbent firm providing access to its downstream rivals does not qualitatively alter our results; for this reason we have decided to present the simplified version and to leave the treatment of the model with the incumbent firm available upon request.[10]

[9] Note that also DSL firms may incur in fixed costs; these costs, that do not play any role in this stylised framework anyway, are usually smaller than those incurred by cable firms since DSL firms do not have the necessity to build their network and can mainly have interconnection with the existing telecom infrastructures. For simplicity we normalise them to zero: F can be interpreted as the difference in fixed costs between DSL and cable firms. As for marginal costs, also cable firms often have to pay the incumbent network for leased lines; for similar reasons as above, these costs are generally lower than those incurred by DSL firms for the unbundled local loop. Therefore we may again interpret c as the difference in marginal costs between DSL and cable firms.

[10] Similarly to the case of an incumbent firm, we have also solved the model in the presence of asymmetry among DSL firms and the qualitative nature of the model remains largely unchanged.

According to the assumptions detailed above, individual firms' profits are

$$\pi_d = (p_d - c)q_i, \qquad \pi_c = p_c y_j - F,$$

where, as above, the subscript d refers to DSL and c to cable. Each firm sets its quantity in order to maximise profits. Solving the first order conditions,[11] it is easy to derive the total amount of broadband access $BB = Q + Y$ at the symmetric equilibrium:[12]

$$BB(c,n,m) = \frac{n\left(\alpha\,\gamma\,m - \beta\,\left(\alpha - c\right)\left(1+m\right)\right)}{\gamma^2 mn - \beta^2\left(1+n\right)\left(1+m\right)} + \frac{m\left(\gamma\,\left(\alpha - c\right)n - \alpha\,\beta\,\left(1+n\right)\right)}{\gamma^2 mn - \beta^2\left(1+n\right)\left(1+m\right)}. \tag{1}$$

Clearly, total access depends on the price for local loop unbundling, c, and on the degree of competition between firms providing DSL and cable services respectively, here represented by the number of firms in the two markets, n and m.

In order to reconcile our theoretical predictions with the results of the empirical analysis provided in the next section, it is useful to discuss in details the two concepts of intra and inter-platform competition. In the empirical exercise we measure the degree of intra and inter-platform competition using the Herfindhal index (HHI), which is usually defined as a sum of firms' squared market size.

The HHI measuring the degree of competition between DSL firms (intra-platform) is simply the sum of the squared firm's relative market share:

$$HHI_{intra}(n,m) = \sum_{i=1}^{n} \frac{q_i^2}{Q^2}.$$

Conversely, we measure the degree of competition across platforms using the following "inter-platform" Herfindhal index based on platforms' market shares:

$$HHI_{inter}(n,m) = \frac{Q^2}{BB^2} + \frac{Y^2}{BB^2}, \tag{2}$$

where Q and Y represent respectively total DSL and cable access, and BB is the total broadband access sold at the equilibrium, as from expression (1).[13]

[11]The first order conditions are

$$\frac{d\pi_d}{dq_i} = -\beta\,q_i + \alpha - \beta\,\left(q_i + \sum_{j\neq i} q_j\right) - \gamma\,\sum_{i=1}^{m} y_i - c = 0,$$

$$\frac{d\pi_c}{dy_j} = -\beta\,y_j + \alpha - \gamma\,\sum_{i=1}^{n} q_i - \beta\,\left(y_j + \sum_{i\neq j} y_i\right) = 0.$$

It is immediate to check that second order conditions are satisfied.

[12]Obtained by setting $q_i = q$ and $y_j = y$.

[13]Note that while HHI_{intra} provides a relative measure of concentration within the DSL technology, HHI_{inter} is a

The evidence from the data, discussed in detail in the next section, reveals that on aggregate intra-platform concentration decreases, confirming a common increasing degree of competition in the DSL segment of the market. Conversely, a similar uniform trend is not observed for inter-platform competition: although HHI_{inter} goes down in most of the countries of the sample, it increases in others (namely Denmark, Ireland, Finland and France).

By construction, HHI_{intra} takes the value of 1 when the market for DSL services is entirely controlled by a single firm, and it decreases as concentration reduces. At the symmetric equilibrium, HHI_{intra} reduces to $1/n$: as n increases, intra-platform competition also increases and the relevant HHI decreases accordingly.[14]

Similarly, HHI_{inter} is equal to 1 when the entire access occurs through a single platform (i.e. "interplatform" concentration is at its maximum), while it takes the value of 1/2 when the two technologies are evenly adopted. Nevertheless, the relationship between the degree of competition between DSL and cable firms, here represented by n and m, and HHI_{inter} defined in (2) is a bit more intricate. Inter-platform concentration may vary either because n changes or because m changes or because they both change.

Let dn and dm indicate respectively the variations in the number of firms providing DSL and cable; according to the current trend in the market for Internet broadband access, both the market of DSL and that of cable access (more generally, the alternative technologies) are experiencing growing competitive conditions. Without loss of relevance, we can restrict our model to the case of $dn > 0$ and $dm > 0$; this implies that HHI_{inter} may increase or decrease depending on the relative magnitude of dn and dm. Formally, in our symmetric framework, two situations may emerge:[15]

1. $dHHI_{inter} < 0$; this may occur if:

   a. DSL is the dominant technology, $Q > Y$ and $dm > dn > 0$: in this case both Q and Y may increase but cable market share increases relatively to DSL and inter-platform concentration decreases.

   b. Cable is the dominant technology, $Y > Q$ and $dn > dm > 0$: in this case both Q and Y may increase but DSL market share increases relatively to cable and, again,

more general measure of the absolute concentration of broadband market. A more comprehensive analysis would have required the use of the Herfindhal indexes also for the segments of cable and other access technologies. Unfortunately, due to a lack of data regarding the number of firms providing access through cable and fiber optics technologies in each country, we are not able to compute the concentration indexes for these alternative forms of broadband access.

[14]This is true also in the case of an incumbent firm that unbundles the local loop to its rivals: in this case, for given c, as n increases, the incumbent's market share in the market for DSL lines decreases and intra-platform concentration also decreases.

[15]A detailed analysis of how variations in n and m affect HHI_{inter} is given in the appendix.

concentration decreases.

2. $dHHI_{inter} > 0$; following exactly the opposite arguments applied above, this may occur if

   c. $Q > Y$ and $dn > dm > 0$.

   d. $Y > Q$ and $dm > dn > 0$.

More generally, as the number of providers, either cable or DSL, gets larger, inter-platform competition increases as long as the market for the dominant technology experiences an increase in the number of firms which is smaller than the increase in the market for the alternative platform.

Note that scenarios b. and d. are of less practical relevance. Apart from Austria and the Netherlands, DSL is by far the dominant technology in Europe; even in the UK, where cable access has historically been very popular, DSL is nowadays the most widespread way of gaining broadband access to the Internet. Accordingly, the theoretical model focuses on the case of $Q > Y$.

We are now ready to derive some testable remarks; remarks 1 and 2 highlight the role of local loop unbundling on broadband diffusion while remark 3, and the subsequent corollary, focus on the distinct effects of intra and inter-platform competition.

Remark 1. The lower the price for local loop unbundling (LLU), the higher broadband adoption:

$$\frac{dBB}{dc} < 0.$$

Remark 2. A reduction in the price of LLU may be more effective in promoting broadband the lower inter-platform concentration; formally:

$$\frac{d\left(\frac{dBB}{dc}\right)}{dHHI_{inter}} > 0 \quad \text{for} \quad \underline{G} < \frac{dn}{dm} < \overline{G},$$

where

$$\overline{G} = -\frac{\frac{\delta HHI_{inter}}{\delta m}}{\frac{\delta HHI_{inter}}{\delta n}} = \frac{n(\alpha - c)[n\alpha(\beta-\gamma) + c\gamma n + \beta\alpha]}{m\alpha[(\alpha - c)\beta(m+1) - \gamma\alpha m)]} > \underline{G} = \frac{n\gamma(\beta + n(\beta - \gamma))}{\beta(m+1)(\beta + m(\beta-\gamma))} > 0$$

Notice that c represents a cost for each DSL firm; therefore the intuition for Remark 1 is obvious: a lower price of LLU enhances the competitive position of DSL firms and this translates into more broadband access sold in the retail market.

According to Remark 2, the stimulating effect of a reduction of the price of LLU on broadband adoption may be more pronounced the higher the degree of inter-platform competition. The practical implication of Remark 2 is that a policy aimed at lowering the price of LLU may be reinforced by pro-competitive measures aimed at stimulating competition between different platforms; this result, that may sound counterintuitive, shows that under certain circumstances these two policies may actually go in the same direction.

The last remark emphasizes the role of inter-platform vs intra-platform competition in stimulating broadband.

Remark 3. The lower the Herfindhal indexes, relative to both inter and intra-platform concentration, the larger total broadband access. Formally:

$$\frac{dBB}{dHHI_{intra}} < 0 \quad \text{and} \quad \frac{dBB}{dHHI_{inter}} < 0.$$

Remark 3 states that, as long as concentration in the two segments of the market decreases, broadband adoption increases; the intuition is obvious: competition induces prices to fall and it stimulates technologies adoption. From this remark, a relevant observation follows:

Corollary 1. Provided that markets become less concentrated, inter-platform competition may be more effective than intra-platform in stimulating broadband uptake. Formally:

$$\frac{dBB}{dHHI_{inter}} < \frac{dBB}{dHHI_{intra}} \quad \text{for} \quad \frac{dn}{dm} > \tilde{G}.$$

where $\tilde{G} = -\frac{\frac{\delta HHI_{inter}}{\delta m}}{\left(\frac{\delta HHI_{inter}}{\delta n} + \frac{1}{n^2}\right)}$.

Both inter-platform and intra-platform competition stimulate adoption through low prices; nevertheless, when not accompanied by a similar pro-competitive policy in the cable segment of the market (formally, when dn/dm is large enough), the impact of intraDSL competition may be partially or entirely smoothed by the negative impact induced by a larger inter-platform concentration. The message is therefore clear: stimulating entry of firms providing DSL access (the dominant technology) certainly induces a decrease in intra-platform concentration, and this has a "direct" positive effect on total broadband. Nevertheless, this policy has also an "indirect" effect that goes in the opposite direction: the induced reduction in concentration across platforms may slow down broadband uptake. When $dn/dm > \tilde{G}$, these two effects go against each other and an effective policy should therefore be aimed at balancing entry in the DSL and in the cable segments of the market, thus exploiting the potentials of both increased inter-platform and intra-platform competition.

The results and implications of this theoretical model are tested in the next section, through an empirical analysis based on data from a sample of EU countries.

5 Evidence from an empirical analysis

5.1 The data

Our panel dataset was built by joining data and information coming from different sources concerning the three broad categories of users and infrastructures, prices and regulatory policies. In particular, all data related to the number of analogic and ISDN digital lines (as well as the number of DSL, CATV, broadband upgraded CATV, fiber optic and satellite lines) were taken from Telecom Markets, a telecom industry newsletter providing quarterly data and statistics detailing fixed-line subscribers and infrastructures broken down by technology. All data on input prices such as unbundling of the local loop, shared access, leased lines one-off and recurring fees, as well as data on the regulation of the rights of way, were taken from the annual reports on the implementation of the telecommunications regulatory package of the European Commission.[16] In many cases data from reports of the European Commission were complemented with data taken from *The Cross Country Analysis*, a bi-monthly publication which provides an overview of the telecom's regulatory situation of Western European Countries.

The dataset contains information on the following countries: Austria (AT), Belgium (BE), Denmark (DK), France (FR), Finland (FI), Germany (DE), Ireland (IE), Italy (IT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Spain (ES), Sweden (SE) and United Kingdom (UK), that is to say all EU-15 countries except Greece, for which we had difficulties in obtaining reliable data on the number of broadband lines. Each country was observed in quarterly time intervals during the period going from the fourth quarter of year 2000 — there are no reliable sources of data on the diffusion of broadband access lines before that date — until the second quarter of 2004, that is the latest period for which data were available at the moment of writing this paper. Our data are available over 15 time periods and 14 countries, but the panel is unbalanced,[17] resulting in a total of 158 observations.

In order to investigate empirically the relationships between broadband uptake and inter/intra platform competition we have built the variables listed below.

PENBB A measure of broadband penetration. Unlike traditional measures of penetration, which weight the number of units of a certain product sold in the market by total population or number of households, our weights the number of broadband lines by the total number of access lines. The number of lines is obtained by dividing the sum of DSL, Cable TV, fiber optic and satellite lines by the the sum of twisted pair copper lines, cable TV lines, fiber optic

[16] In particular, data for year 2000 were taken from the sixth report, data for year 2001 from the seventh report and so on until year 2003.

[17] Because, for example, not all the countries had mandated local loop unbundling as early as at the end of 2000.

and satellite lines. Thus, *strictu sensu*, our indicator measures the number of all possible access lines that have been upgraded to transmit high-speed data.

INTRA An index measuring the level of market concentration/competition within the DSL technological platform. As already mentioned in Section 4 our measure of competition (or the lack thereof) is the standard Herfindhal index.

INTER An index measuring the level of market competition/concentration across different technological platforms. As already mentioned, we measure competition (or the lack thereof) across different technological platforms using a particular version of the Herfindhal index which is not computed over firms' market shares, but over technologies' market shares.

ROW1 A dichotomous variable taking the value of 1 when rights of way and digging permits over public land are granted by a single central authority and 0 when rights of way are granted by local authorities.

ROW2 A dichotomous variable taking the value of 1 when operators experience delays in getting rights of way or digging permits and 0 when no delays are reported.

LLU12 A variable that measures the price of an unbundled copper local loop. It is obtained by adding one third of the one-off charge to the yearly fee (i.e. the yearly quota of the one-off charge).[18]

LLP A variable that measures the price of a leased line. It is obtained by adding the one-off fee to the annual charge of 2 kilometers 2Mbps leased line.

LCC The price of a ten minutes local call on the incumbent's fixed network (including the call set-up fee).

In Table 1 we present some figures on the evolution of inter and intra platform competition in the 14 European countries over the time considered by our analysis.[19] The table shows a general trend toward a more competitive DSL market. In fact, apart from a few exceptions – namely Belgium, Denmark, Finland, and Italy – all countries have experienced increasing levels of competition in the DSL segment of the market. The dynamic of inter-platform competition is generally slower than that of intra-platform competition. In some countries, such as Denmark, Spain, Finland and France, the Herfindhal Index for inter-platform competition has actually increased through time, suggesting a worsening of the competitive conditions across alternative platforms. The difficulties of

[18] We are therefore distributing the common cost of the one-off charge over three years.

[19] Table 1 shows only three time observations of the 14 time observations of our dataset.

Table 1: Number of DSL and alternative BB subscriptions, and measures of platform competition in Europe

	DSL			NODSL			INTRA			INTER		
	'01q2	'02q4	'04q1	'01q2	'02q4	'04q1	'01q2	'02q4	'04q1	'01q2	'02q4	'04q1
AT	69,600	179,600	314,800	122,000	277,000	355,000	0.88	0.68	0.60	0.54	0.52	0.50
BE	94,000	519,100	905,000	180,000	353,481	517,000	0.68	0.73	0.69	0.55	0.52	0.54
DE	1,350,000	3,295,000	4,885,000	24,300	53,800	100,000	1.00	0.89	0.82	0.97	0.97	0.96
DK	74,516	306,944	518,000	59,034	151,415	230,580	0.51	0.69	0.67	0.51	0.56	0.57
ES	157,702	960,303	1,871,613	54,000	344,981	598,000	0.78	0.64	0.67	0.62	0.61	0.63
FI	27,400	219,000	500,000	25,000	54,000	96,000	0.59	0.68	0.67	0.50	0.68	0.73
FR	177,000	1,410,358	3,665,010	163,302	282,992	431,000	0.82	0.59	0.51	0.50	0.72	0.81
IE	0	3,300	32,100	0	7,300	8,390		0.68	0.52		0.57	0.67
IT	239,000	925,000	2,865,000	14,500	88,050	173,190	0.51	0.57	0.55	0.89	0.84	0.89
LU	550	6,822	16,080	20	150	510	1.00	0.93	0.70	0.93	0.96	0.94
NL	62,000	333,000	951,000	300,000	760,809	998,000	0.94	0.58	0.52	0.72	0.58	0.50
PT	1,000	52,044	238,341	55,765	207,486	339,345	0.91	0.70	0.75	0.97	0.68	0.52
SE	93,765	419,000	564,500	165,250	291,400	419,000	0.96	0.63	0.61	0.54	0.52	0.51
UK	72,000	590,100	2,234,850	76,892	781,819	1,490,300	0.58	0.50	0.51	0.50	0.51	0.52

fostering and establishing competition between different access technologies can easily be explained by the magnitude of the investments necessary to deploy alternative infrastructures. This also explains why at the end of the period that we consider, DSL is the dominant technology in the majority of the countries.

5.2 Econometric specification and estimation results

In order to test the implications of the theoretical model presented above, an econometric analysis has been conducted, based on the evidence obtained for the mentioned 14 EU countries. In particular, the following models have been estimated

$$\begin{aligned}\mathrm{PENBB}_{i,t} \quad = \quad & \mathrm{const} + \text{time effects} + \beta_1 \mathrm{LLP}_{i,t} + \beta_2 \mathrm{LLU12}_{i,t} + \beta_3 \mathrm{LCC}_{i,t} \\ & + \beta_4 \mathrm{ROW1}_{i,t} + \beta_5 \mathrm{ROW2}_{i,t} + \beta_6 \mathrm{INTRA}_{i,t} + \beta_7 \mathrm{INTER}_{i,t} \\ & + \beta_8 \mathrm{INTER}_{i,t} * \mathrm{LLP}_{i,t} + \beta_9 \mathrm{INTER}_{i,t} * \mathrm{LLU12}_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{3}$$

$$\mathrm{PENBB}_{i,t} \quad = \quad \mathrm{const} + \text{time effects} + \beta_1 \mathrm{LLP}_{i,t} + \beta_2 \mathrm{LLU12}_{i,t} + \beta_3 \mathrm{LCC}_{i,t}$$

$$+\beta_4\text{INTRA}_{i,t} + \beta_5\text{INTER}_{i,t} + \beta_6\text{INTER}_{i,t} * \text{LLP}_{i,t}$$
$$+\beta_7\text{INTER}_{i,t} * \text{LLU12}_{i,t} + \varepsilon_{i,t} \quad (4)$$

and

$$\begin{aligned}\text{PENBB}_{i,t} &= \text{const} + \text{time effects} + \beta_1\text{LLP}_{i,t} + \beta_2\text{LLU12}_{i,t} + \beta_3\text{LCC}_{i,t} \\ &\quad +\beta_4\text{INTRA}_{i,t} + \beta_5\text{INTER}_{i,t} + \beta_6\text{INTER}_{i,t} * \text{LLP}_{i,t} \\ &\quad +\beta_7\text{INTER}_{i,t} * \text{LLU12}_{i,t} + \beta_8\text{GDPPC}_{i,t} + \varepsilon_{i,t}, \qquad (5)\end{aligned}$$

where $\varepsilon_{i,t}$ is an error term and model (5) controls for GDP per capita (in real terms). Models (3), (4) and (5) can be estimated using well known panel data techniques.[20] Time trend components have been accounted for including time effects in the estimated equations. As for the constant term, both the Fixed Effects (FE) and Random Effects (RE) specifications have been estimated and tested. Also, given the way the measures of inter and intra platform competition have been constructed, there may be some concerns as to what extent they can be treated as exogenous variables. Therefore an Instrumental Variable (IV) regression has been performed, instrumenting the competition measures with their lagged values. Finally, we explicitly treat the price of unbundling the local loop, LLU12, as exogenous, since this variable is typically regulated and therefore is not endogenously determined. The results of the estimation exercise, reported in Table 2, reveal some interesting facts and provides answers to the implications of the theoretical model of Section 4.

First, as predicted by Remark 1, the price of the local loop unbundling has a negative effect on the diffusion of the broadband. This confirms the importance of local loop unbundling, which is one of the main strategies adopted by competitive broadband access providers in the DSL segment of the market: the price that they pay for each unbundled line affects directly their operating costs.

Also, strictly related to this finding is the negative and significant effect of the price of leased lines. These are in fact an important input for the provision of DSL services and therefore are expected to be inversely related to the diffusion of broadband services.

The price of local calls is, as expected, positively related with the diffusion of broadband (except for model (3) estimated with IV). In fact, being the primary vehicle through which narrow band Internet access is provided, an increase in the price of local calls should push customers towards the adoption of broadband access to the Internet. The sign shows that the price of narrow band Internet

[20] The theoretical model described in Section 4 is static; therefore static regressions have been estimated. Using dynamic panel data techniques, also a dynamic version of the model has been estimated, by including the lagged value of $\text{PENBB}_{i,t}$ among the regressors. However, the test for the validity of the moment restrictions imposed by the resulting generalized method of moments estimator massively rejects the null hypothesis and therefore the results of the dynamic regression are statistically insignificant.

access constrains the diffusion (through the price) of broadband access, suggesting that, at least to a certain extent, narrow band and broadband access services are in the same relevant market; but the fact that the coefficient is not statistically significant confirms some previous findings in related literature which place the two products in separate markets.[21]

The coefficient related to the first Rights of Way variable has the expected sign (in fact one should expect less delay under centralised authority granting rights of way to broadband access providers), but is not statistically significant (except in the FE regression) and it seems that, at least at this stage, centralisation of provision of the rights of way has not played a significant role in the diffusion of broad band technology. The same can be said about the second coefficient related to the granting of the Rights of Ways; the (expected) negative results in the regression outputs (except in the FE regression), but the coefficient is once again not statistically significant. Therefore the variables indicating the concession of Rights of Way are dropped in the alternative specifications of models (4) and (5).

The Herfindhal Index expressing the level of competition between alternative technological platforms is negative and statistically significant. This confirms the findings of the theoretical model, namely those of Remark 3. Therefore competition between different platforms seems to be one of the main drivers of broadband uptake. This is an interesting result and it provides a statistical support to what has been often claimed by industry experts (see DotEcon and Criterion Economics, 2003).

The Herfindhal Index expressing the level of competition within each technological platform (in this case, due to data availability, only competition within DSL has been taken into account) is positive, but insignificant. Also, the coefficient is numerically much smaller than the one related to the interplatform competition Index and very close to zero; this supports the theoretical prediction provided in Corollary 1. The intuition behind this result is that, although competition between DSL firms can potentially play an important role in promoting broadband diffusion, this effect seems to be completely overwhelmed by the negative "indirect" effect of increased inter-platform competition induced by promoting entry into the DSL segment of the market.

The terms involving cross products between the LLP, LLU12 and the inter-platform measure of competition are both positive and significant. This implies that the positive effect on broadband diffusion of lower prices of LLU will be more pronounced the lower the degree of concentration across markets. The implications of these empirical findings seem to be consistent with the theoretical predictions of the model. In particular, the stimulating effect of a reduction in the price of LLU

[21] DotEcon and Criterion Economics (2003) indicate that the extent of substitutability between narrow band and broadband access services is quite limited and only in the direction from narrow band to broadband; in any case, it is insufficient to suggest that they lie in the same relevant market. Similar evidence is in Hausman et al. (2001).

will be reinforced by a high level of competition between technological platforms, as predicted in Remark 2.

Finally, it is worth noticing that the signs and significance of the estimated parameters remain fairly constant across the different specifications estimated. In particular, for models (3), (4) and (5), the outcome of the Hausman test reveals that the instrumental variable specification seems to be the one consistent with data. In fact, in all the cases the null hypotheses that there is no systematic difference between the RE and IV estimators is rejected. This confirms the concerns about the possible endogeneity of the computed inter and intra platform competition indexes and suggests the need of instrumenting them.[22]

6 Conclusions

This paper focuses on the distinct roles played by inter-platform and intra-platform competition in stimulating broadband adoption. This is a highly debated issue in the digital economy among both practitioners and policy makers.

While stimulating entry into the DSL segment of the market through appropriate regulatory policies, such as local loop unbundling, is generally less problematic then enticing entry into alternative platforms (typically cable and fiber optics), it is still very much unclear which is the most effective way to proceed in order to speed up broadband adoption.

By moving from a simple model of oligopolistic competition between access providers of different platforms, we explicitly estimate the impact of intra-platform and inter-platform competition on broadband uptake. Our empirical evidence, based on data for 14 European countries, confirms the theoretical predictions of the model; in particular, our results emphasize the role of stronger competition across technologies as the main driver to stimulate broadband adoption. Conversely, the enhanced competition within the DSL segment of the market does not seem to have played a similar role; furthermore, we have also shown, both theoretically and empirically, that there are positive synergies to be exploited between policies directed to induce more inter-platform competition and those directed towards local loop unbundling.

We view our results as a first step at understanding the effects of various forms of competition on broadband adoption. The adoption process is clearly at its early stages; should more complete data become available, we will investigate further on these complex relationships.

[22]The FE and RE regressions give very similar outcomes, and the related Hausman test for the hypothesis of no difference between the two estimators does not reject the null in two cases out of three, namely models (3) and (5).

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Appendix

The relationship between HHI_{inter} and the level of competition m and n. In this section we discuss how the Herfindhal index for inter-platform competition, defined in (2), varies when the number of firms in the two segments of the market change. By assumption, we restrict the attention to the case of increasing competition in both segments: $dn > 0$ and $dm > 0$. Totally differentiating (2) yields

$$dHHI_{inter} = \frac{\delta HHI_{inter}}{\delta m} dm + \frac{\delta HHI_{inter}}{\delta n} dn. \tag{6}$$

We want to characterise the sign of this differential. Two cases emerge: i) DSL is the dominant technology, $Q > Y$ and ii) cable dominates, $Y > Q$.

We start with case i), which is the current situation in most countries; in our symmetric equilibrium, it must be that $\frac{\delta HHI_{inter}}{\delta n} > 0$ and $\frac{\delta HHI_{inter}}{\delta m} < 0$: an increase in the number of DSL firms induces the market to tip even further towards DSL while an increase in the number of cable firms makes technologies more evenly adopted. Therefore, from expression (6):

$$dHHI_{inter} < 0 \qquad \text{if} \qquad \frac{dn}{dm} < -\frac{\frac{\delta HHI_{inter}}{\delta m}}{\frac{\delta HHI_{inter}}{\delta n}}. \tag{7}$$

Using the equilibrium output values Q and Y given in (1), we can compute HHI_{inter}:

$$\begin{aligned} HHI_{inter} \;=\; & \frac{(mn\gamma)^2\left(c^2+2\alpha^2-2c\alpha\right)-2\alpha mn\left(2mn+n+m\right)\left(\alpha-c\right)\beta\gamma}{\left(\alpha\left(\beta\left(n+m\right)+2mn\left(\beta-\gamma\right)\right)-\left(\beta+m\left(\beta-\gamma\right)\right)nc\right)^2} \\ & +\frac{\left(\left(n\left(m+1\right)c\right)^2-2\alpha n^2\left(m+1\right)^2c+\alpha^2\left(2m^2n^2+2m^2n+2n^2m+m^2+n^2\right)\right)\beta^2}{\left(\alpha\left(\beta\left(n+m\right)+2mn\left(\beta-\gamma\right)\right)-\left(\beta+m\left(\beta-\gamma\right)\right)nc\right)^2}. \end{aligned}$$

Differentiating HHI_{inter} with respect to n and m, inequality (7) becomes:

$$\frac{dn}{dm} < \frac{n(\alpha-c)[n\alpha(\beta-\gamma)+c\gamma n+\beta\alpha]}{m\alpha[(\alpha-c)\beta(m+1)-\gamma\alpha m)]}.$$

Let

$$\overline{G} = \frac{n(\alpha-c)[n\alpha(\beta-\gamma)+c\gamma n+\beta\alpha]}{m\alpha[(\alpha-c)\beta(m+1)-\gamma\alpha m)]}.$$

$\overline{G}$ is positive for any admissible value of the LLU, c.[23] Therefore, $dHHI_{inter} < 0$ when dn/dm is small enough, namely when m increases relatively more than n; in this case, both Q and Y increase but cable market increases relatively to DSL and, consequently, concentration decreases. HHI_{inter} increases when the opposite occurs.

[23] It can be shown, but the intuition is straightforward, that when the price of LLU is too high, the market for DSL access disappears. In order to guarantee the existence of the model, $Q \geq 0$, we need to impose $c \leq \bar{c}$, where $\bar{c} = \frac{\alpha\,(\beta+m(\beta-\gamma))}{(m+1)\beta}$.

Case ii) occurs when cable is the dominant technology, $Y > Q$. In this case, as $dn > 0$ and $dm > 0$, the Herfindhal index varies with an opposite sign: $\frac{\delta HHI_{inter}}{\delta n} < 0$ and $\frac{\delta HHI_{inter}}{\delta m} > 0$; an increase in the number of cable firms induces the market to tip even further towards cable while an increase in the number of DSL firms makes technologies more evenly adopted. Therefore, the discussion on $dHHI_{inter}$ follows the same lines as above, although with reversed inequalities, and it is omitted for brevity.

Summarizing, as the number of providers gets larger, inter-platform competition increases as long as the market for the dominant technology experiences an increase in the number of firms which is smaller than the increase in the market for the alternative platform. □

Proof of Remark 1. Remark 1 can be easily proved by simple differentiation of expression (1):

$$\frac{dBB}{dc} = -\frac{n(\beta(m+1) - \gamma m)}{\beta^2 (1+n)(1+m) - \gamma^2 mn} < 0. \tag{8}$$

Since $\beta > \gamma$ and $n > m$, the above condition is always satisfied. □

Proof of Remark 2. We need to determine under which conditions

$$\frac{d(\frac{dBB}{dc})}{dHHI_{inter}} > 0.$$

This inequality holds when the variations $d(\frac{dBB}{dc})$ and $dHHI_{inter}$ are of the same sign. The sign of $dHHI_{inter}$ has been already determined in the first section of the Appendix.

In order to investigate the sign of $d(\frac{dBB}{dc})$, take the total differential of (8)

$$\begin{aligned} d\left(\frac{dBB}{dc}\right) &= \\ &= -\frac{(\beta + m(\beta-\gamma))\beta^2(m+1)}{\left(\beta^2(m+n+nm) + mn(\beta^2-\gamma^2)\right)^2} dn + \frac{(\beta + n(\beta-\gamma))\gamma\beta n}{\left(\beta^2(m+n+nm) + mn(\beta^2-\gamma^2)\right)^2} dm. \end{aligned} \tag{9}$$

From this expression, it is clear that $d(\frac{dBB}{dc}) > 0$ if

$$\frac{dn}{dm} < \frac{n\gamma(\beta + n(\beta-\gamma))}{\beta(m+1)(\beta + m(\beta-\gamma))},$$

and it is negative otherwise. Let

$$\underline{G} = \frac{n\gamma(\beta + n(\beta-\gamma))}{\beta(m+1)(\beta + m(\beta-\gamma))}.$$

Through simple algebraic manipulations, it can be shown that for any admissible value of the parameters, $\overline{G} > \underline{G} > 0$, where $\overline{G}$ has been defined in the first section of the Appendix.[24] Therefore

[24]Formally, this inequality is verified for any $c \leq \bar{c}$. The proof of this statement is quite long and it is therefore omitted for brevity. We leave it available upon request.

it follows that

$$\frac{d(\frac{dBB}{dc})}{dHHI_{inter}} > 0,$$

when $\underline{G} < \frac{dn}{dm} < \overline{G}$. This proves the remark. $\square$

Proof of Remark 3. We need to show that, when markets become less concentrated ($dHHI_{intra} < 0$ and $dHHI_{inter} < 0$) the equilibrium number of broadband access lines increases, i.e. $dBB > 0$.
We start with inter-platform concentration: from the results in the first section of the Appendix, we know that $dHHI_{inter} < 0$ when $dn/dm < \overline{G}$.
Consider now total broadband access BB; taking the total differential of (1) and rearranging we obtain:

$$dBB = \frac{\beta\,(\beta + m\,(\beta - \gamma))\,(\beta\,(\alpha - c)\,(m+1) - \alpha\,\gamma\,m)}{\left(\gamma^2 mn - \beta^2\,(n+1)\,(m+1)\right)^2}\,dn + \frac{\beta\,(\beta + n(\beta - \gamma))\,(\beta\alpha - \alpha\gamma n + \beta n\alpha + c\gamma n)}{\left(\gamma^2 mn - \beta^2\,(n+1)\,(m+1)\right)^2}\,dm.$$

From visual inspection is easy to verify that, when $dn > 0$ and $dm > 0$, $dBB > 0$ for any admissible value of c.
Therefore, when $dHHI_{inter} < 0$, $dBB > 0$: this prove the first part of the remark.
Consider the impact of intra-platform competition. As seen above, $dBB > 0$ when the numbers of DSL and cable firms increase; since $dHHI_{intra} < 0$ when $dn > 0$, then $dBB/dHHI_{intra} < 0$. $\square$

Proof of Corollary 1. When both the cable and the DSL segments of the market become more competitive, i.e. $dn > 0$ and $dm > 0$, then inter-platform competition is more effective then intra-platform competition in promoting broadband access when

$$\frac{dBB}{dHHI_{inter}} < \frac{dBB}{dHHI_{intra}} \quad \Rightarrow \quad dHHI_{inter} > dHHI_{intra}.$$

Since, $dHHI_{intra} = -1/n^2$, this inequality simply reduces to

$$\left(\frac{\delta HHI_{inter}}{\delta n} + \frac{1}{n^2}\right) dn + \frac{\delta HHI_{inter}}{\delta m}\,dm > 0.$$

Let $\tilde{G} = -\frac{\frac{\delta HHI_{inter}}{\delta m}}{\left(\frac{\delta HHI_{inter}}{\delta n} + \frac{1}{n^2}\right)}$. Then the last expression can be rewritten as

$$\frac{dn}{dm} > \tilde{G}.$$

From the first section of the Appendix, we know that $dHHI_{inter} < 0$ for $\frac{dn}{dm} < \overline{G}$, where

$$\overline{G} = -\frac{\frac{\delta HHI_{inter}}{\delta m}}{\frac{\delta HHI_{inter}}{\delta n}} = \frac{n(\alpha - c)[n\alpha(\beta - \gamma) + c\gamma n + \beta\alpha]}{m\alpha[(\alpha - c)\beta(m+1) - \gamma\alpha m)]}.$$

It is clear that, for any $n > 0$, $\overline{G} > \tilde{G}$; therefore, for $\tilde{G} < \frac{dn}{dm} < \overline{G}$, Corollary 1 is satisfied. $\square$

Table 2: Panel regression results (figures in parentheses refer to t statistics for coefficients and to p values for tests)

Model	Model (3)			Model (4)			Model (5)		
Specification	FE	RE	IV	FE	RE	IV	FE	RE	IV
LLP	−.000013 (−1.74)	−.000015 (−1.85)	−.000034 (−3.21)	−.000017 (−1.91)	−.000018 (−2.09)	−.000047 (−3.29)	−.000016 (−1.88)	−.000012 (−1.90)	−.000049 (−3.47)
LLU12	−.001132 (−2.47)	−.001074 (−3.50)	−.002866 (−6.01)	−.000986 (−2.19)	−.001013 (−2.74)	−.004590 (−4.95)	−.001050 (−2.25)	−.001054 (−3.76)	−.004305 (−5.26)
LCC	.002255 (1.89)	.000377 (0.77)	−.000438 (−1.25)	.000338 (0.43)	.000306 (0.50)	.000230 (0.30)	.000347 (0.44)	.000233 (0.97)	.000004 (0.26)
ROW1	.028359 (1.75)	.024886 (1.15)	.037957 (1.22)						
ROW2	.042631 (1.56)	−.018344 (−0.90)	−.012642 (−0.85)						
INTRA	.036425 (1.21)	.029877 (1.12)	.019254 (0.48)	.035520 (1.20)	.029175 (1.00)	.079600 (1.56)	.033196 (1.11)	.037216 (1.20)	.084855 (1.51)
INTER	−.436742 (−2.98)	−.480193 (−4.14)	−1.385403 (−6.80)	−.430215 (−2.91)	−.461642 (−3.61)	−2.049935 (−5.35)	−.447763 (−2.97)	−.516465 (−4.87)	−1.981164 (−5.71)
INTER * LLP	.000011 (1.84)	.000018 (1.89)	.000052 (3.28)	.000019 (1.71)	.000020 (1.88)	.000066 (3.27)	.000019 (1.69)	.000012 (1.75)	.000067 (3.37)
INTER * LLU12	.001369 (2.42)	.001295 (2.93)	.004093 (5.37)	.001263 (2.22)	.001284 (2.62)	.006434 (4.84)	.001331 (2.30)	.001352 (3.04)	.006215 (5.09)
GDPPC							−.170796 (−0.65)	−.005246 (−0.55)	−.046609 (−1.78)
CONST	.245760 (1.95)	.361696 (4.00)	.979764 (6.78)	.337798 (2.81)	.364345 (3.57)	1.437544 (5.44)	2.103706 (0.77)	.471882 (3.62)	1.825138 (4.57)
R^2	0.53	0.64	0.59	0.60	0.63	0.55	0.24	0.62	0.58
LM test		126.95 (0.00)			127.55 (0.00)			164.08 (0.00)	
Hausman (RE vs. FE)	15.56 (0.11)			29.07 (0.00)			6.96 (0.64)		
Hausman (RE vs. IV)		29.42 (0.00)			17.89 (0.02)			17.67 (0.04)	
Wald (joint)	34.71 (0.00)	506.40 (0.00)	273.42 (0.00)	40.37 (0.00)	468.90 (0.00)	195.63 (0.00)	36.58 (0.00)	938.60 (0.00)	194.43 (0.00)